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Long standing Japanese-German polarized solid target collaboration (1968 - 2015)

Naoaki Horikawa* **E-mail:** nao6510@isc.chubu.ac.jp

The Japanese-German collaboration is focused on the study of polarization phenomena and in particular on the development of polarized solid targets (PT). This collaboration is lasting for more than 45 years and started in late 1960s between the universities of Nagoya and Bonn. In this report, I will present the history of this creative collaboration, which can be divided into three stages, corresponding to the time periods of 1968 – 1980 (1st stage), 1980 – 1995 (2nd stage) and 1995 – present (3rd stage). For each stage, the research subjects, developments of PT technologies and group-member exchanges are mentioned.

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*Speaker.

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1. Introduction

Japan and Germany have a long collaboration history for more than 45 years, studying spin dependent phenomena at high particle energies. In this time and until today, polarized solid targets (PT) are essential to entangle the spin properties in such experiments. In this report, the collaboration activities are divided into three stages by their time periods. The first stage covers the years from 1968 to 1980, whereas the second stage continues then to 1995 and the third stage still goes on until today. In every stage, the physical research subjects, new PT technologies and the exchange of staff members are discussed.

2. Japanese-German Collaboration

Before discussing the different stages, I want to give a brief overview over the Nagoya PT activities in the 1960s. At that time, supervisor Prof. S. Hayakawa had already decided to construct a polarized target system in collaboration with Prof. K. Nishimura from the Kyoto university. They planned an experiment to measure the spin correlation parameters A_{yy} and A_{xx} in order to investigate the L-S force in two-nucleon collisions. In 1969, the experiment was accomplished, using the 50 MeV protons from the cyclotron at INS (Institute for Nuclear Study, Tokyo). This was the 3rd or 4th earliest PT experiment in the world. The parameters of this PT system were as follows: A magnetic field of 1.8 T and a temperature of 1 K, maintained by a ^{4}He refrigerator. The target material was LMN (lanthanum magnesium nitrate), with a maximum proton polarization of 35%. The A_{yy} and A_{xx} parameters have been measured successfully[1], where the polarized secondarily proton beam had a polarization degree of 50%, produced by colliding protons with a Ca target.

2.1 1st Stage (1968 - 1980)

After the successful $p^{\uparrow}p^{\uparrow}$ scattering experiment, the group of Nagoya decided to use polarized targets for the high energy experiments at the 700 MeV electron synchrotron, already constructed at INS few years before. Almost at the same time, Prof. K.H. Althoff (Bonn, Germany) had also planned to use polarized targets for experiments at a 2.5 GeV electron synchrotron. Both institutes intended to investigate the nucleon structure through the pion-photoproduction process, by particularly using PT technology. In the 1970s, the PT systems in Nagoya and Bonn used 2.5 T magnets, ^{3}He refrigerators and alcohol targets, like butanol or propanediol. The obtained target asymmetry parameters T(Θ) have contributed to the establishment of the nucleon resonances and the phenomenological analysis, together with the differential cross section $\sigma(\Theta)$, recoil nucleon polarization P(Θ) and incident photon asymmetry Σ(Θ).

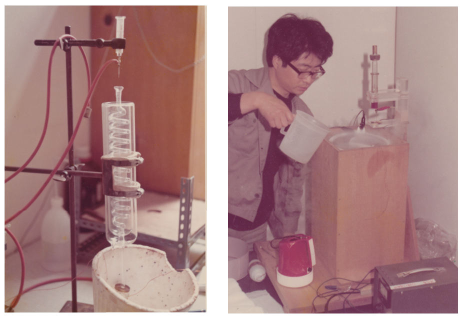

Figure 1: Method for production of frozen alcohol sphere. **Left:** Bonn method **Right:** Nagoya method.

One example of the technology exchange was the production method of the target material, for example

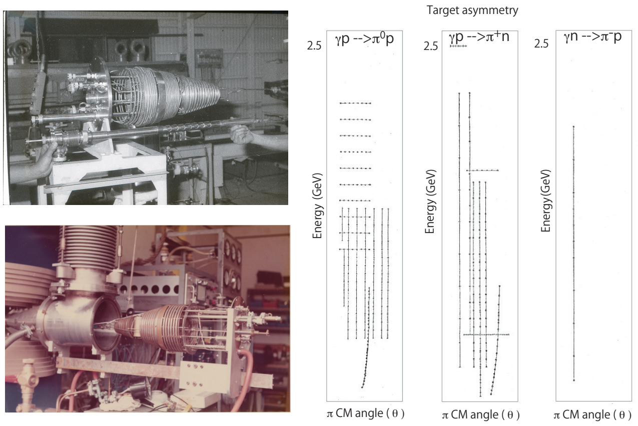

Figure 2: Left upper and lower : PT system in Nagoya and Bonn. Right : Plot for measured target asymmmetry parameters T(θ) for 3 different processes.

Multiplet	Resonance	Amplitude	Nagoya	Glasgow
(56, 0+)0	P33(1232)	$A_{1/2}$	-138 ± 4	-136 ± 6
		$A_{3/2}$	-259 ± 6	-247 ± 10
(70, 1−)1	S11(1535)	$A_{1/2}$	77 ± 21	65 ± 16
	S11(1650)	$A_{1/2}$	50 ± 10	31 ± 17
	D13(1520)	$A_{1/2}$	-7 ± 4	-19 ± 7
		$A_{3/2}$	168 ± 13	167 ± 10
	D13(1700)	$A_{1/2}$	-2 ± 13	-24 ± 19
		$A_{3/2}$	29 ± 14	-17 ± 14
	D15(1670)	$A_{1/2}$	34 ± 5	23 ± 15
		$A_{3/2}$	24 ± 8	3 ± 12
	S31(1650)	$A_{1/2}$	10 ± 5	21 ± 20
	D33(1670)	$A_{1/2}$	89 ± 33	125 ± 22
		$A_{3/2}$	60 ± 15	102 ± 15
(56, 0+)2	P11(1470)	$A_{1/2}$	-63 ± 8	-68 ± 15
(70, 0+)2	P11(1710)	$A_{1/2}$	28 ± 9	15 ± 25
(56, 2+)2	F15(1690)	$A_{1/2}$	-9 ± 6	-18 ± 14
		$A_{3/2}$	115 ± 8	141 ± 14

Table 1: Resonance amplitudes derived from data by different groups.

Table 2: Exchanged staff members during the 1st stage.

year	Bonn to Nagoya	Nagoya to Bonn
1971	H.Herr	A.Masaike
1973	P.Feller(2years)	R.Kajikawa
	K.H.Althoff	
	H.Fischer	
	W.Schwille	
1975		T.Yamaki(2 years)
1976	P.Noelle(2 years)	
1977		N.Horikawa(2 years)
1978	W.Schwille	
	V.Burkert	

the alcohol beads. In Bonn, the beads were produced using a corrugated glass tube, in which the alcohol droplets flowed with liquid nitrogen through the glass pipe, resulted in frozen alcohol spheres at the end of the slide. In Nagoya, this method was tested, but not successfully, probably as a consequence of small differences in the glass structure of the tube. Therefore, an improvement was implemented by using static electricity. Charged-up droplets have the advantage, that they can freeze out without sticking together, due to the repulsive force of the electrical charge. In Figure 1, the apparatus of Bonn and Nagoya are shown. In Figure 2, the low-temperature refrigerators of both institutes are shown, as well as the target asymmetry. Table 1 gives an overview of the analyzed results.

The exchange of the staff members in this 1st stage was as follows. From Bonn, 8 people visited Nagoya. Two of them stayed 2 years as members of the Nagoya group. In return, 4 people from Nagoya visited Bonn, two of them stayed in the partner group for 2 years, as well. As it can be seen from Table 2, I stayed from 1977 to 1979 in Bonn. When I joined the polarized target group of Bonn, Prof. K.H. Althoff gave me two major tasks to do. First, I had to give a lecture on the principles of the dilution cooling mechanism – due to Prof. K.H. Althoff's request in German language – and afterwards I should design a dilution cryostat. Concerning the design of the dilution cryostat, I calculated the heat input and cooling efficiency for a Niinikooski-type horizontal refrigerator, discussing with Dr. Meyer. The responsibility and efforts for the construction of the cryostat were taken by H. Peschel and was finished up to the ^{3}He cooling stage, when I left for Nagoya.

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2.2 2nd Stage (1981 - 1995)

In this stage, the PT development, including the construction of the dilution cryostat, has been progressed in both Bonn and Nagoya. In parallel, the development of the polarized electron source has become one of the main subjects. At KEK, as the study of the polarized proton beam acceleration has started, the proposed experiment by Nagoya was approved. In Bonn, the dilution cryostat was finished under the supervision of Dr. W. Meyer and was used for high energy experiments. Moreover, he and his group performed many other technical developments for a wider use of PT. Some of them are:

1. establishment of an irradiation method for solid NH_3
2. advance in practical use of LiH, LiD as polarized targets
3. manufacturing of superconducting thin coil magnets for frozen spin targets
4. construction of a new NMR system, controllable with LabVIEW
5. study of high power IMPATT-diodes

Those developments contributed significantly to the experiments in Bonn, Mainz and later at CERN. On the other hand in Nagoya, the dilution refrigerator was also constructed for the $p^{\uparrow}n^{\uparrow}$ scattering experiment at KEK, studying the quark-quark interaction in nucleon collisions. The proposal for the $p^{\uparrow}n^{\uparrow}$ experiment has been accepted in 1983 with the restriction, that it should be started after a successful acceleration to 10 GeV. We used NH_3 as a target material and obtained polarization values of 75%. We were ready for the replacement of NH_3 with ND_3, when the beam energy should reached 10 GeV, but unfortunately the beam energy could not be brought up to 10 GeV in 1988 and so the proposal had to be discarded. Therefore, the Nagoya group joined the SMC collaboration at CERN, after the experiments with $p\uparrow d$ scattering at 3.5GeV[2].

Table 3: Exchanged staff members during the 2nd stage.

year	Bonn to Nagoya	Nagoya to Bonn
1984		N.Horikawa
		T.Nakanishi
1986	W.Meyer(3 months)	T.Nakanishi(18 months): $e^{\uparrow}$
	D.Menze	
1987	K.H.Althoff	
1988	W.Schwille	N.Horikawa
	D.Husmann	T.Nakanishi
1989		N.Horikawa
		T.Iwata(each twice)
1990		N.Horikawa
		T.Nakanishi
1992	K.H.Althoff	N.Horikawa
	, W.Meyer	
1993	D.Menze(3 months)	S.Nakamura(7 years): $e^{\uparrow}$
1994		N.Horikawa

The study of polarized electron sources were being continued during my stay in Bonn by Dr. Drachenfels. I decided to start the same subject in Nagoya for further applications to high energy experiments, after going back to Japan. Collaborating with Dr. Nakanishi, we started our research in 1980 and published the first paper[3] in 1986. In this stage, the physical subject was mainly the role of the quarks in the nucleon. In Bonn[4] and Nagoya[5], the search of dibaryon resonances through the photodisintegration of the deuteron has been achieved successfully. The aim of the $p^{\uparrow}n^{\uparrow}$ scattering at KEK has been realized by the SMC collaboration at CERN. Since 1989, the Nagoya group concentrated their efforts in the SMC and COMPASS collaboration. Around 1990, Dr. W. Meyer shared the same interests in physics and joined the $g_1(x)$ measurements at SLAC, due to an invitation of Prof. C. Prescott. After he came back to Bonn 15 months later, he became a full professor at the Ruhr-University of Bochum and founded a powerful laboratory for

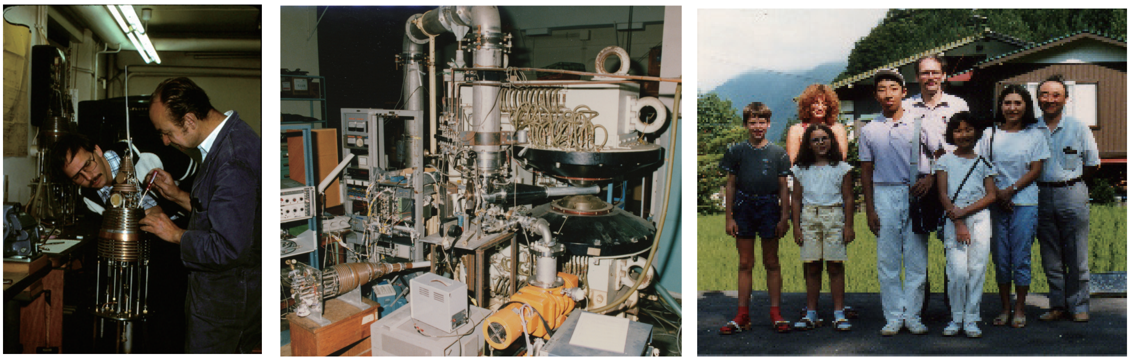

Figure 3: Left: Bonn dilution cryostat, **Center:** Nagoya PT system, **Right:** Meyer's Family in Shin-Hodaka with Horikawa's one.

spin physics. The member exchange in this stage is shown in Table 3. Figure 3 shows the dilution cryostat, which was built in Bonn, the PT system in Nagoya and the Meyer and Horikawa family in Shin-Hodaka.

2.3 3rd Stage (1995 - present)

In this stage, the main part of the Japanese-German collaboration moved to the COMPASS experiment at CERN, in which both, Nagoya and Bochum have participated. In 2003, I have retired from Nagoya University and Prof. T. Iwata of Yamagata has been the successor of the Japanese COMPASS group leader.

At the beginning of the COMPASS collaboration, the Japanese groups (Nagoya, KEK, Miyazaki) contributed mainly to the construction of the huge superconducting magnet and the preparation of the microwave system, whereas the German groups (Bochum, Bielefeld) contributed to the preparation of the target materials (Butanol, NH_3, LiD), construction of the NMR systems, fabrication of the target holder and the microwave systems. Besides those visible contribution, Prof. W. Meyer has contributed to an invisible part, the employment of COMPASS PT members for more than over 10 years. Without this support, COMPASS PT could not have been operated successfully.

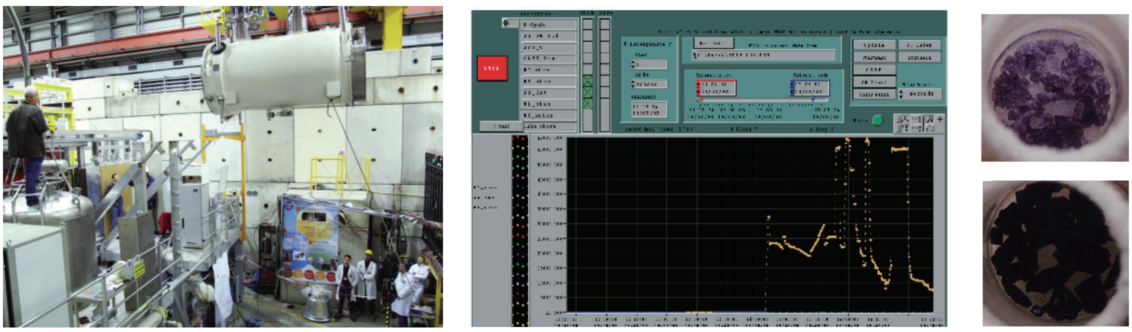

Figure 4: Left: COMPASS magnet, **Center:** NMR monitor system, **Right:** Target material (upper: NH_3, lower: LiD)

The Nagoya-Mainz collaboration started in 1995, with the A-2 group managed by Prof. H.J. Arends. The main topic of the collaboration was the test of the GDH (Gerasimov-Drell-Hearn) sum-rule in spin dependent meson photoproduction. One part of this topic was the measurement of the helicity dependent cross section of the η meson photoproduction process, using frozen spin targets. In this time, the student S. Hasegawa joined from Nagoya and got his Ph.D[6] related to this topic. The collaboration between Yamagata and Bochum started roughly around 2005, when Prof. T. Iwata was the supervisor of the Japanese COMPASS group. One of the main topics of this collaboration was the study of polarized thin polymer targets (CH_2 and CD_2). This subject was intended for a low energy experiment in Nagoya, in which $D^{\uparrow}D^{\uparrow}$ collisions are used for the fundamental investigation of polarized fusion. Dr. Wang Li got her Master of Science degree in 2003 and restarted further studies on polymer targets by joining the Bochum PT group. She has finished the work for her doctoral thesis after almost 10 years of study and got her Ph.D from the Yamagata university under the supervision of Prof. T. Iwata. Dr. N. Doshita and Dr. K. Horikawa Kondo who were postdocs of Yamagata, were financially supported by Prof. W. Meyer for some years and work for the polarized target at COMPASS until now.

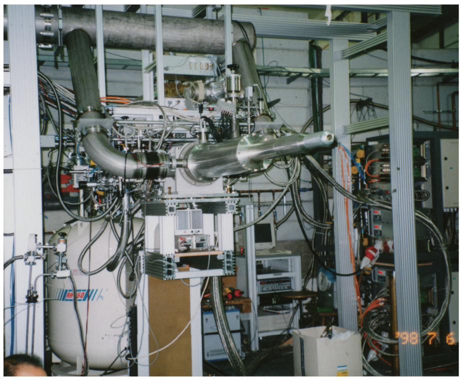

Figure 5: The Mainz frozen target system.

Table 4: German staffs visited Japan during the 3rd stage.

year	Germany to Japan
1997	W.Meyer(Bochum)
1998	G.Reicherz(Bochum)
	A.Thomas(Mainz)
1999	W.Meyer(2 months)
2000	H.Ahrends(Mainz)
2002	G.Reicherz
	A.Thomas
2003	W.Meyer
2005	G.Reicherz(2 months to Yamagata)
	E.Radke and C.Hess(Bochum)

In such a way, the connection between Yamagata and Bochum became stronger, just like the former Nagoya-Bonn relation. The exchange of the group members was intensively progressed. Especially after the start of COMPASS measurements in 2001, Japanese group members (N. Horikawa, T. Iwata and T. Hasegawa) visited Bonn and Bochum frequently on the way to CERN. After my retirement as supervisor of the Japanese COMPASS group, I have no exact record of the staff exchange anymore. Therefore in Table 4, I listed up only the German members who visited Japan before 2005.

3. Summary and Acknowledgment

Here, I have summarized the history of Japanese-German longstanding collaboration.

1. The collaboration on solid PT and spin physics between Japan and Germany lasts more than 45 years successfully, which started from the Nagoya-Bonn collaboration in late 1960s.
2. Later, it expanded to the Nagoya-Bochum, Nagoya-Mainz and Yamagata-Bochum collaborations.

3. The Japanese-German collaboration is very effective in the research of spin physics and progressing the related projects.

The key of the successful collaboration is the mutual trust and respect. I would also say, that the long standing collaboration pushes the understanding of history, culture and nationality of each partner, which had helped to create a peaceful and friendly relationship between both countries.

I would like to express my special thanks to Prof. W. Meyer and the former supervisor Prof. K.H. Althoff (Bonn University), for their kind and warm arrangements and for the successful collaboration. And I would also thank deeply the Alexander von Humboldt Foundation (AvH) and Japan Society for the Promotion of Science (JSPS), for their kind care and powerful supports.

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